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# Assessment of Tubing Type on Ammonia Gas Adsorption

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# ASSESSMENT OF TUBING TYPE ON AMMONIA GAS ADSORPTION

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**ABSTRACT.** *Different types of tubing and operating conditions may be involved when measuring ammonia ($NH_3$) concentrations and its emissions from animal production facilities. Prices of commercially available tubing vary substantially. A question that has often come up but has not been well investigated is how the tubing type (e.g., PVC vs. FEP) may impact the certainty of $NH_3$ concentration measurement. The study reported here was conducted to address this issue in that it assessed and compared the magnitude of $NH_3$ adsorption to different types of commercially available tubing under conditions that may be present in animal feeding operation (AFO) air emission studies. The types of tubing evaluated were: Teflon (PFA and FEP tubing), HDPE (clear plastic tubing), and PVC (vinyl tubing). Each tested tubing had a length of 30.5 m (100 ft) and an inside diameter of 6.35 mm (0.25 in.). Five nominal $NH_3$ levels of 10, 20, 40, 80, and 160 ppm, generated with poultry manure, were passed through the tested tubing at an airflow rate of 8 L min$^{-1}$ (0.28 CFM) for 60 min. Simultaneous measurements of $NH_3$ concentrations at the inlet and outlet of the tested tubing were made with two photoacoustic gas spectrometers (1% repeatability of measured value and 0.2-ppm $NH_3$ detection limit). Although the Teflon tubing had significantly lower $NH_3$ adsorption than the HDPE or PVC tubing, all the tested tubing showed <3% $NH_3$ differences between the inlet and outlet concentrations after the 60-min exposure and mostly <1% for $NH_3$ levels >40 ppm. The results of this study thus suggest that the HDPE and PVC tubing offer viable, more economical air sampling options for AFO $NH_3$ emission studies.*

***Keywords.*** *Air sampling, Ammonia adsorption, Teflon tubing, HDPE tubing, PVC tubing.*

Ammonia ($NH_3$) is a major noxious gas emitted from animal, especially poultry, feeding operations (AFO). When emitted to the atmosphere, it may have negative environmental impacts by inducing acidification in soils and water bodies (Vranken et al., 2004). $NH_3$ has also been reported to be a precursor to $N_2O$ (Clemens and Ahlgrimm, 2001). Reliable measurements of $NH_3$ emissions from AFO are critical for evaluating effectiveness of potential mitigation techniques as well as for establishing fair and equitable regulations (Wathes et al., 1998).

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Previous studies have used various methods and instruments to measure $NH_3$ concentrations in animal facilities, including electrochemical sensors (Xin et al., 2002, 2003; Liang et al., 2004; Gates et al., 2005), chemiluminescence detector (Phillips et al., 1998; Heber et al., 2001), and photoacoustic spectrometer (Zhang et al., 2005; Burns et al., 2006; Dong et al., 2009). Regardless of the working principles of the gas analyzers or monitors, tubing is generally needed to deliver the air sample from the sampling location to the monitoring device. Albeit limited, studies have shown different types of tubing to have various degrees of $NH_3$ adsorption. Mukhtar et al. (2003) evaluated two types of tubing, Teflon (PTFE) and low density polyethylene (LDPE) (inside diameter of 3.2 mm or 0.125 in.) for $NH_3$ adsorption under the following test conditions: six nominal $NH_3$ concentrations of 2, 5, 10, 15, 25, and 35 ppm; two nominal temperatures of 25°C and 37°C (77°F and 99°F); two tubing lengths of 15 and 46 m (50 and 150 ft); flow rate of 2 L min$^{-1}$ (0.07 cubic feet per minute or CFM); and an exposure time of 60 min. Mukhtar et al. (2003) reported that $NH_3$ adsorption onto the LDPE tubing was significantly higher than onto the Teflon® tubing; and that the adsorption to the LDPE tubing was affected by temperature, tubing length, and gas concentration, although tubing length did not significantly affect $NH_3$ adsorption onto the Teflon tubing. Capareda et al. (2004) investigated the adsorption of $NH_3$ on 46- and 90-m Teflon tubing and showed negligible adsorption of $NH_3$ onto the Teflon tubing. Shah et al. (2006) evaluated $NH_3$ adsorption characteristics of five tubing types, namely, polytetrafluoroethylene (PTFE), perfluoroalkoxy (PFA), fluorinated ethylene propylene (FEP), high density polyethylene (HDPE), and polyvinyl chloride (PVC) [all with inside diameter of 4.76 mm

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(0.188 in.) except for the HDPE with inside diameter of 4.32 mm (0.17 in.)], at two nominal $NH_3$ concentrations of 1 and 10 ppm, a tubing length of 2.5 m (8.2 ft), flow rate of approximately 10 L $min^{-1}$ (0.35 CFM), and an exposure time of 120 min. Shah et al. (2006) reported no significant differences in $NH_3$ adsorption among the tested tubing, hence the least expensive PVC tubing would provide the best option under the test conditions.

As a safeguard to sampling integrity, it is a common practice for researchers to use some type of Teflon tubing for $NH_3$-laden air sampling because of its inert nature to most chemicals, low coefficient of friction, and low permeability to gases and water vapor (Baker and Mead, 2000). While Teflon tubing has these advantages over alternative sampling tubing materials, its significantly higher cost often presents challenges to affordability. Moreover, when dealing with air sampling and emissions from animal production facilities, gaseous concentrations under certain situations (e.g., wintertime in high-rise manure storage areas) can be high enough that a less inert tubing type may suffice. This is particularly the case when considering the uncertainty associated with the determination of building ventilation rate (VR) in the calculation of gaseous emissions from the source. A building emission uncertainty analysis by Gates et al. (2009) indicates that unless the uncertainty of VR can be controlled within 2.5% (a daunting target), a concentration measurement uncertainty of 0.5% versus 5% makes little difference in the estimation of building emissions. Therefore further investigation of using alternative air sampling tubing for air emissions applications is warranted.

The objective of this study was to evaluate the magnitude of $NH_3$ adsorption onto four commercial types of tubing, namely, PFA, FEP, PVC, and HDPE at nominal $NH_3$ concentration levels of 10, 20, 40, 80, and 160 ppm. Each tested tubing had the length of 30.5 m (100 ft) and an inside diameter of 6.35 mm (0.25 in.). The $NH_3$-laden air passed through the tubing at 8 L $min^{-1}$ (0.28 CFM) for 60 min.

## Materials and Methods

### Measurement System Setup

Ammonia concentration of the air entering and exiting the test tubing was measured simultaneously using two photoacoustic multi-gas spectrometers (model 1412, Innova AirTech Instrument, Denmark; ammonia filter UA 0974; detection limit of 0.2 ppm; and 1% repeatability of measured value). The analyzers automatically compensate for moisture, carbon dioxide, temperature, or pressure variation. Simultaneous measurements at both inlet and outlet with two analyzers were to minimize the impact of inherent fluctuations in the source $NH_3$ concentration on the results. One analyzer could have been used to avoid differences caused by the instruments if the $NH_3$ concentration had been held constant; however variation was inevitable for the source of $NH_3$ gas generated with poultry manure. It took approximately 120 s for the analyzer to reach 95% to 97% of the true concentration readings (Moody et al., 2008). The evaluation system (fig. 1) was located inside an environmentally controlled room [20.6°C (69°F)]. Prior to each tubing test, zero ($N_2$) and span (22.6 ppm $NH_3$ + $N_2$ balance, ±2% accuracy) calibration gases (Matheson Tri-Gas, Inc., La Porte, Tex.) were used to check both analyzers to ensure their repeatability and exchangeability. In addition, for the first 10 min or more of each tubing test, both analyzers were connected to the same poultry-manure $NH_3$ source, via a <1-m long Teflon tubing, to ensure the same operational characteristics of the analyzers as determined in the zero/span check. The absolute differences between the two gas analyzers, from the zero/span checks, were <1.3% (fig. 2) or <0.27 ppm. Hence, differences >1.3% or >0.27 ppm in $NH_3$ concentration between inlet and outlet indicate existence of measurable $NH_3$ adsorption. Similarly, smaller differences mean that the adsorption was below the detection of the analyzers.

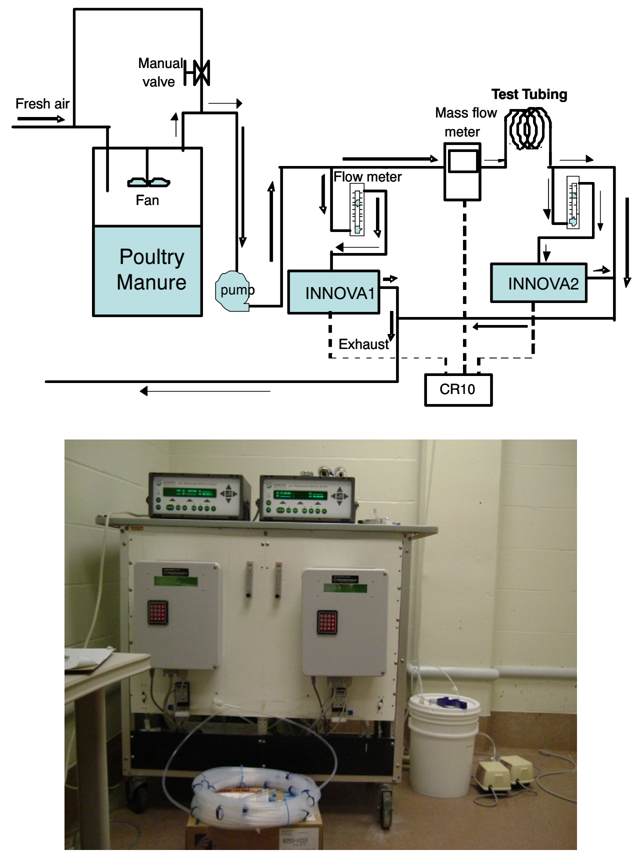


**Figure 1. Schematic (top) and photographic (bottom) representation of the experimental setup for evaluating impact of tubing type on ammonia ($NH_3$) gas adsorption.**

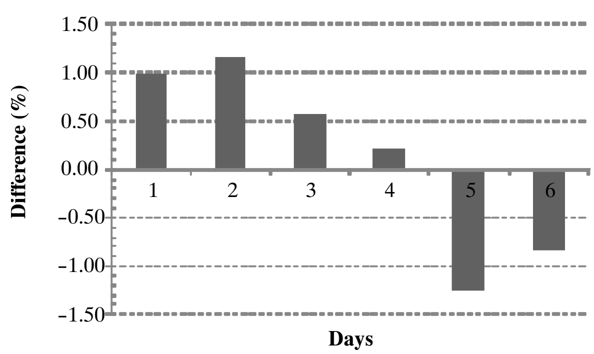


**Figure 2. Exchangeability of the two photoacoustic infrared gas analyzers (INNOVA 1412) as measured by their differences in $NH_3$ span gas (22.6 ppm) readings from daily checks. Each span check lasted for about 15 min and the data shown represent means of about 20 readings.**

For the evaluation of tubing $NH_3$ adsorption, poultry manure held in a 19-L (5-gal) container with a mixing fan was used to generate $NH_3$ (fig. 1). Different $NH_3$ concentrations were achieved by controlling the amount of fresh air entering the manure container. Airflow rate through the tubing was measured using a mass flow meter (SS wetted part, 0-10 *l*/min, McMillan Company, Georgetown, Tex.). A programmable measurement and control module (CR10X, Campbell Scientific, Inc, Logan, Utah) was used to sample the analog output from the gas analyzers, the mass flow meter and an ambient temperature/RH probe at 2-s intervals and stored as 1-min averages.

### Types of Tubing Evaluated and Test Conditions

Four types of commercially available tubing that might be used in sampling of $NH_3$-laden air for air emissions studies were tested in this study, including two types of Teflon tubing: (a) FEP (Thermo Fisher Scientific Inc., Rochester, N.Y.) and (b) PFA (Parker-TexLoc, Fort Worth, Tex.), a PVC type (Kuriyama of America, Inc., Schaumburg, Ill.), and an HDPE type (Thermo Fisher Scientific Inc., Rochester, N.Y.). Each treatment regimen was replicated twice, using new tubing for each run. The tubing characteristics and the test conditions used in the study are listed in table 1.

### Statistical Analysis

The amounts of tubing $NH_3$ adsorption were analyzed using Proc GLM of SAS (SAS, 2000, Cary, N.C.) to determine difference among the tubing types under each $NH_3$ level. Differences were considered significant at $p<0.05$.

## Results and Discussion

The mean $NH_3$ adsorption by the four types of tubing during the 60-min exposure period is summarized in table 2. The HDPE tubing had significantly greater adsorption than the FEP or PFA tubing at all five $NH_3$ levels ($p<0.05$), but no significant difference when compared to the PVC tubing except at 20 and 160 ppm. The PVC tubing had significantly greater adsorption than the FEP or PFA tubing for $NH_3$ levels ≥ 40 ppm. There was no significant difference between the two Teflon tubing types (p=0.06-0.93) except at 40 ppm.

Representative temporal patterns of $NH_3$ absorption by the tubing over the 60-min period are shown in figure 3 for 20- and 80-ppm $NH_3$ concentrations. It can be seen that the differences between the inlet and outlet became by and large constant after 5 to 30 min of exposure. The time it takes to reach the steadiness depends on the tubing type and $NH_3$ level, with the Teflon tubing or higher $NH_3$ levels (for a given tubing type) taking shorter time.

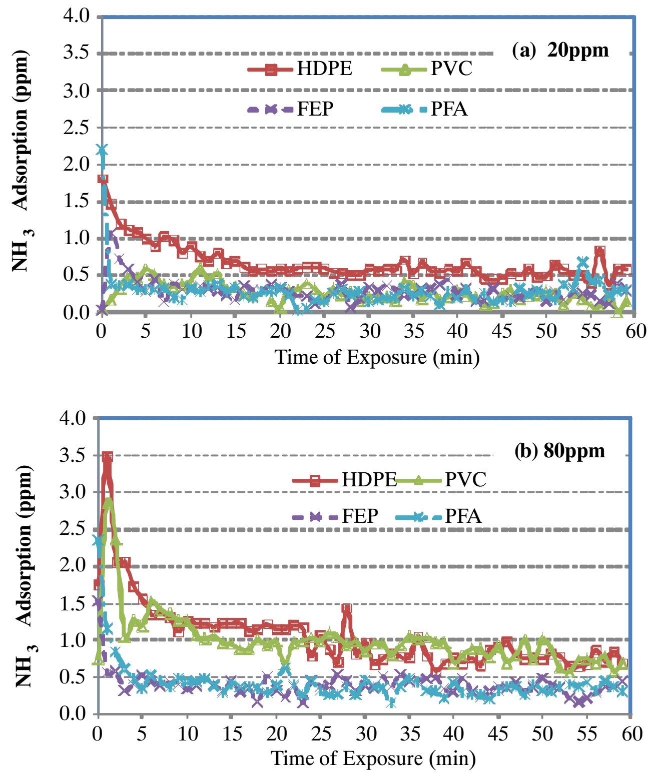


**Figure 3. Representative $NH_3$ absorption by the four types of tubing at a given $NH_3$ concentration [(a) 20 ppm, (b) 80 ppm] [tubing length = 30.5 m (100 ft); tubing inside diameter = 6.35 mm (0.25 in.); flow rate = 8 L min$^{-1}$ (0.28 CFM)].**

**Table 1. Tubing type, flow rate and $NH_3$ concentrations used in this study.**

| Tubing Type | Material | O.D. (mm) | I.D. (mm) | Length (m) | Flow Rate (L min$^{-1}$) | Nominal $NH_3$ Level (ppm)[a] |
|---|---|---|---|---|---|---|
| HDPE | High density polyethylene | 9.5 | 6.35 | 30.5 | 8 | 10, 20, 40, 80, 160 |
| PVC | PVC compound | 9.5 | | | | |
| FEP | Fluorinated ethylene propylene | 7.9 | | | | |
| PFA | Perfluroalkoxy polymer | 9.5 | | | | |

[a] The actual $NH_3$ concentrations corresponding to the nominal values of 10, 20, 40, 80 and 160 ppm were, respectively, 9.0 to 10.3, 18.8 to 22.9, 38.4 to 42.6, 78.8 to 81.7, and 156 to 164 ppm.

Unit conversion: 1 m = 3.28 ft, 1 mm = 0.03937 in., 1 *l* min$^{-1}$ = 0.0353 cubic feet per minute (CFM)

**Table 2. Mean ammonia ($NH_3$) adsorption by the four types of 30.5-m tubing over 60-min exposure to different $NH_3$ concentrations, expressed as differences between inlet and outlet $NH_3$ concentration (Mean ± SE).**

| Tubing Type | Nominal $NH_3$ Concentration (ppm)[a] | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 40 | 80 | 160 |
| HDPE | 0.22±0.01$^{a}$ | 0.68±0.03$^{a}$ | 0.51±0.04$^{a}$ | 1.06±0.06$^{a}$ | 2.35±0.17$^{a}$ |
| PVC | 0.19±0.01$^{ab}$ | 0.27±0.02$^{b}$ | 0.58±0.03$^{a}$ | 1.0±0.05$^{a}$ | 1.59±0.09$^{b}$ |
| FEP | 0.14±0.02$^{c}$ | 0.29±0.02$^{b}$ | 0.21±0.01$^{c}$ | 0.4±0.02$^{b}$ | 0.55±0.04$^{c}$ |
| PFA | 0.17±0.02$^{bc}$ | 0.30±0.03$^{b}$ | 0.32±0.03$^{b}$ | 0.43±0.04$^{b}$ | 0.67±0.07$^{c}$ |

[a] For a given nominal $NH_3$ concentration, values with different superscript letters are significantly different (p < 0.05).

The adsorption characteristics (both absolute and relative magnitude) of the tested tubing are summarized in table 3 after 15-, 30-, and 60-min exposure to the various $NH_3$ levels. It can be noted that after 60-min exposure/conditioning, the reduction in outlet $NH_3$ readings of all the tubing were <3% for the $NH_3$ levels tested (10 to 160 ppm), with the higher relative reduction corresponding to the lower $NH_3$ levels. Specifically, the relative reduction was 2.7%, 2.5%, and 1.0%, respectively, for HDPE, FEP, and PFA tubing at 10-ppm nominal $NH_3$ level, as compared to 0.9%, 0.0%, and -0.1%, respectively, at 160-ppm nominal $NH_3$ level. For $NH_3$ levels ≥ 40 ppm, the differences were mostly <1%. Considering there was an inherent discrepancy of up to ±1.3% or 0.27 ppm (at 22.6 ppm) in $NH_3$ readings between the two gas analyzers, a relative difference within ±1.3% or <0.27 ppm would be considered to be below the detection of the instruments. Shah et al. (2006) reported that $NH_3$ adsorption by various types of 2.5-m long tubing (PTFE, PFA, FEP, HDPE, and PVC) ranged from 0.10% to 0.58% at 10-ppm concentration over a 2-h exposure. The difference in $NH_3$ "adsorption" between the current study and that by Shah et al. (2006) could have arisen from differences in tubing length, runtime, and $NH_3$ concentrations.

Gates et al. (2009) reported that unless the uncertainty of building VR could be controlled within 2.5% (a formidable target), a concentration measurement uncertainty of 0.5% versus 5% makes little difference in estimation of building emissions. Hence, results from the current study demonstrate that any of the tubing types may be used in AFO $NH_3$ emissions studies without tangibly compromising the data certainty or quality, especially when gas analyzers with the similar sensitivity as that used in the current study (considered as one of the most advanced and reliable instruments on the market) is used for concentration measurement. The HDPE or PVC type tubing is much more economical than the FEP or PFA Teflon type.

## Conclusions

Ammonia ($NH_3$) adsorption characteristics were evaluated for four types of commercially available tubing that may be used in studies of $NH_3$ emissions from animal feeding operations, i.e., PFA Teflon, FEP Teflon, HDPE, and PVC tubing. Each type of tubing [30.5 m (100 ft) long, 6.35 mm (0.25 in.) i.d.] was subjected to five nominal inlet $NH_3$ concentrations (10, 20, 40, 80, and 160 ppm, generated with poultry manure) at 8 L min$^{-1}$ (0.28 CFM) of air flow rate for 60 min of exposure.

Although the Teflon tubing was found to have significantly lower $NH_3$ adsorption than the HDPE and the PVC tubing, all the tested tubing types showed <3% relative reduction of $NH_3$ readings following the 60-min exposure. Moreover, differences in $NH_3$ readings were mostly <1% (lower than the inherent discrepancy of ±1.3% between the two gas analyzers used in the test) when $NH_3$ levels exceed 40 ppm. Hence the HDPE and PVC tubing tested in this study offer viable, more economical options for use in air emission studies, especially for air samples with relatively high $NH_3$ concentrations.

**Table 3. Ammonia ($NH_3$) adsorption by different types of tubing (30.5 m or 100 ft long and 6.35 mm or 0.25 in. I.D.) when air samples of 10-, 20-, 40-, 80-, or 160-ppm nominal $NH_3$ concentrations passed through at a flow rate of 8 L min$^{-1}$ (0.28 CFM) for 60 min (n = 2).[a]**

| Tubing Type | Nominal $NH_3$ Level (ppm) | Absolute Reduction (Mean±SE, ppm) after Exposure Time (min) of: | | | Relative Reduction (Mean±SE, %) after Exposure Time (min) of: | | |
|---|---|---|---|---|---|---|---|
| | | 15 | 30 | 60 | 15 | 30 | 60 |
| HDPE | 10 | 0.02±0.22 | 0.2±0.24 | 0.3±0.11 | 0.2±2.16 | 2.2±2.40 | 2.7±1.20 |
| | 20 | 0.7±0.47 | 0.5±0.34 | 0.6±0.53 | 3.5±2.48 | 2.7±1.78 | 3.0±2.81 |
| | 40 | 0.6±0.41 | 0.3±0.27 | 0.4±0.21 | 1.4±1.05 | 0.8±0.69 | 1.0±0.52 |
| | 80 | 1.2±0.50 | 0.8±0.15 | 0.7±0.37 | 1.5±0.62 | 1.0±0.19 | 0.9±0.46 |
| | 160 | 1.7±0.35 | 1.8±0.20 | 1.4±0.22 | 1.0±0.21 | 1.2±0.15 | 0.9±0.17 |
| PVC | 10 | 0.2±0.09 | 0.2±0.08 | 0.07±0.04 | 1.6±0.37 | 1.6±0.07 | 0.4±0.08 |
| | 20 | 0.3±0.0 | 0.2±0.04 | 0.2±0.11 | 1.5±0.09 | 0.8±0.26 | 0.7±0.54 |
| | 40 | 0.6±0.26 | 0.4±0.28 | 0.3±0.24 | 1.6±0.63 | 0.9±0.67 | 0.8±0.58 |
| | 80 | 1.0±0.07 | 1.0±0.18 | 0.7±0.10 | 1.2±0.14 | 1.1±0.12 | 0.9±0.16 |
| | 160 | 1.2±0.20 | 2.2±0.78 | 1.2±0.58 | 0.8±0.12 | 1.4±0.49 | 0.8±0.39 |
| FEP | 10 | 0.02±0.12 | 0.0±0.21 | 0.2±0.13 | 0.3±1.21 | 0.01±2.07 | 2.5±1.21 |
| | 20 | 0.2±0.09 | 0.20.18 | 0.3±0.19 | 1.2±0.47 | 0.9±0.92 | 1.8±0.98 |
| | 40 | 0.3±0.00 | -0.1±0.12 | 0.6±0.36 | 0.7±0.02 | -0.22±0.29 | 1.7±1.04 |
| | 80 | 0.3±0.38 | 0.3±0.28 | 0.5±0.15 | 0.4±0.48 | 0.4±0.36 | 0.6±0.18 |
| | 160 | 0.6±0.43 | 0.8±0.20 | 0.0±0.03 | 0.4±0.27 | 0.5±0.13 | 0.0±0.02 |
| PFA | 10 | 0.0±0.01 | 0.2±0.05 | 0.1±0.13 | -0.04±0.13 | 1.8±0.60 | 1.0±1.43 |
| | 20 | 0.3±0.15 | 0.3±0.18 | 0.3±0.04 | 1.4±0.77 | 1.4±0.87 | 1.5±0.26 |
| | 40 | 0.4±0.00 | 0.3±0.09 | 0.2±0.14 | 0.9±0.01 | 0.8±0.23 | 0.5±0.34 |
| | 80 | 0.3±0.25 | 0.25±0.18 | 0.3±0.27 | 0.4±0.31 | 0.3±0.23 | 0.4±0.35 |
| | 160 | 0.8±0.20 | 0.4±0.05 | -0.2±0.17 | 0.5±0.12 | 0.3±0.04 | -0.1±0.10 |

[a] The discrepancy in $NH_3$ readings of span calibration gas between the two analyzers was < |±1.3%|. Hence, differences < |±1.3%| should be considered as below the detection limit of the instrument.

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